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THE NEW LLRF SYSTEM: THEORY OF OPERATION AND RECOMMENDATIONS FOR FUTURE UPGRADES

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OVERVIEW

It was long recognized that it was theoretically possible to accelerate a beam in the AGS using a "programmed rf function;" the problem was lack of need and insufficient level of technology. The advent of cheap but powerful microprocessors and the development of digitally programmed, phased locked, frequency synthesizers has recently provided the needed technology; the HITL project provided the impetus to change from our traditional "bootstrapped" rf solution to a "programmed" approach.

Refined over a twenty year period, the "bootstrapped" method is an excellent solution to our historical mission, but the need to accelerate various ion species with wide variations in beam intensity demanded a new solution which would give both a stable and a flexible answer to rf beam control.

Assigned the development of a new low level rf system capable of accelerating a wide diversity of particle types, over a large range of beam intensities without the need for beam generated position or phase information feedback, we were forced to use this newly available technology. The selected approach required the design and construction of various novel subsystems including a dual processor computerized device controller, a frequency synthesizer based signal generator with both digital and analog driving functions, optional phase and position feedback and a "learn mode" analyzer for "open loop" operation.

THEORY OF OPERATION

Acceleration is carried out via two types of rf cavities. There are 10 high frequency cavities which sweep from 2.5 to 4.5 mHz for both protons and heavy ions, and one low frequency cavity which sweeps from .5 to 2.5 mHz.

The rf frequency range corresponds to the 12th harmonic of the revolution rate of the beam about the AGS circumference.

The beam's performance is determined by the functional relationship which exists between magnetic field, gap volts and rf frequency/phase.

Siemens' control determines the magnetic cycle; a set of values for field is obtained from the main ring magnets via a Gauss clock. The rf must follow these Gauss clock values, so one of the microprocessors is used to retrieve from common memory a large table of frequency values corresponding to selected values of the Siemens' derived Gauss clock (number of ticks).

These values are sent to a frequency synthesizer which generates the actual rf drive signals.

The particular synthesizer was selected because it had a phase continuous mode; unfortunately this device lacks capability beyond 3 mHz. Therefore, a frequency doubler stage was introduced to provide the .5 to 4.5 mHz output range required. The doubler module also contains the rf switches and delay needed for the transition jump.

The computer circuitry is asked to output some six bytes of information for each field selected frequency point. It can do this in some 10 microseconds. Directly supporting the selected frequency point are three bytes. Two additional bytes provide mode selection and Gauss clock countdown values and loop switching information requires one byte. Six bytes are also readback by each computed Gauss clock event. These include the corrected frequency point (3 bytes), command status information (one byte, e.g. loops open/closed) and an available analog input channel (2 bytes).

Since the learn mode requires that both a frequency point be inputed and outputed for every Gauss clock step, the maximum update rate obtainable is just under 50 kHz. As the maximum Gauss clock rate can reach 117 kHz, a divide by power of N circuit is provided to shift gears much as a car does.

The frequency step size provided by each stored value varies as a function of machine field. At injection for heavy ions it is typically 1 kHz. The high field steps are limited to the 2 cycle resolution provided by the synthesizer and attached doubler. Since it was believed (Raka et al.) that a "safe" jump was bout 75 cycles at injection, it was decided to incorporate a frequency interpolator circuit. This circuit adds 1/16 of the interval between two computer generated steps at a rate which "fills in" the coarser generated staircase.

An alternate approach which would store more steps was judged to be more limited in rate and to require an insupportable amount of stored memory data. The size of the present table(s) is already some 350,000 bytes each.

The second microprocessor is used as a network link into the central control complex. This device controller can calculate the required frequency tables from a short set of downloaded parameters; it also collects status information for analysis of performance and maintenance purposes.

If this complexity wasn't enough, there are several analog and digital signals which must be recognized as modifiers and switches needed for beam control. The digital signals were relatively easy to implement, but the analog corrections required the addition of a high speed (5 mHz max rate) analog to digital converter whose output must be summed with the computer generated values and the interpolator generated steps into a single value with which to feed the frequency systhesizer.

As with all electronics, the selected synthesizer has quirks of its own which require several layers of code converters and adders to overcome.

The end result is a system with considerable fundamental merit, but also one which was complicated and difficult to implement.

NOTE: Some of the preceding material was taken from an "Operations Guide to the AGS Low Level rf System" edited by D. Pope, with the following list of contributors: D. Barton, M. D'Azzo, R. Frankel, M. Iwantschuk, V. Kovarik, B. Oerter, A. Otis, M. Pritsker, P. Rosas, R. Wankentien.

STATUS

An operational model of the system exists along with a limited set of spare parts. A basically sound software program exists at both the device controller and host level for operation usage.

RECOMMENDATIONS

I. Mechanical Assembly Issues

As built, the existing LLRF system is a mix of multibus computer boards, Eurocard sized interface circuitry and NIM analog modules, housed and interconnected using LEMO, BNC, Ribbon and NIM connectors arranged in NIM crates, computer chassis and Eurocard cages. This design is a relic of the way the different project subgroups each worked on their design assignments.

There are several grave weaknesses associated with this construction approach. There are many more connectors and connections than is strictl necessary. The usage of packages is not matched to their application andy construction techniques for digital circuits are not always the best ones for analog circuits, etc.

The existing system is prone to failure because of the large number of connectors used, the line drivers required by these interconnections, and because the circuits themselves are a mix of printed circuits, wire-wrap and hand soldered construction, many of which have been heavily reworked. The system is also hard to "trouble shoot" because circuit modularity is not coincident with circuit functionality.

II. System Integration Issues

The individual circuit sections are not arranged in logical groups, therefore most module failures cannot be isolated. A redesign of system modularity should be made to correct this problem.

While there are some useful displays, more test points and indicator lights are needed for rapid performance evaluation and repair.

The use of power supplies is fragmented; there are probably more units than necessary for the task at hand. Higher reliability can be achieved by the elimination of some units and the rearrangement of others. Perhaps a few large, high power units might be better.

All equipment in the mezzanine work area, including the AGS and rf amplifier modules, should be treated as a unified low level rf package. After all, the beam is down just as badly whether a failure is in the controlling computer or a line drive rf amplifier.

III. Availability Issues

As an operation facility of considerable importance and complexity, the only way to guarantee sufficient availability, up time, is to have TWO complete systems and a scattering of spare parts. Thus, any non-trivial system failure can be overcome by switching to the backup system. The failed system can then be repaired off-line using the spare parts inventory. Because systems of this class are so complex that they cannot be repaired with basic tools and test instruments, one needs a complete system as both a spare and as a test set.

IV. Low Level rf Lab and Maintenance Area

A good idea would be to convert the currently unused work area on the mezzanine floor to a low level rf lab and repair depot. The third and remaining room on this floor can be used as temporary office space by individuals working on llrf problems.

V. Training and Documentation

Several technicians should be trained in the operation, maintenance and repair of the new low level rf system. At least one engineer should be selected as the systems engineer for this facility. His/Her training must include the use AND generation of test programs.

Documentation should be completed. It should include schematics, operation descriptions, photographs of external and internal signals, as well as programs (operational and diagnostic) in both paper and media format.

VI. Software Changes

Beyond those changes called for by hardware redesign, there is a need for improved operation and maintenance programs. This is not to say that the present programs are inadequate, but to indicate a further need to exploit the equipment constructed and to allow repair.

VII. Necessary Design Changes and Improvements

1. The existing low level rf system now will only run effectively in closed beam loop mode. We must develop and design alternate methods of phase and position control which would allow operation without a beam signal. The information for this adjustor could be obtained from any or all of the following signals: BEAM, Magnet Current, rf gap voltage.

Interface of this information could be at the signal summer to the frequency synthesizer or via a phase corrector located at the frequency synthesizer output. The final choice should be made after a review of our recent run and current CERN results.

2. It has already been determined that correct operation of the radial loop, and of the phase loop, is coupled to the net time delay through the analog/digital and frequency synthesizer circuitry. This delay is now estimated to be 11 microseconds when all rf delays are included. Such a delay is acceptable, but performance in closed loop mode may be improved by reduction.

The sampling rate of the analog loop system should be raised to the maximum obtainable. Converted analog and interpolation information should be inserted into the frequency determining register in the correct order for minimal "glitch" generation. One should attempt to raise loop response and reduce loop delays to the best level possible.

3. The present design provides a fixed, not remote controllable, delay for phase transition. It is desirable and possibly necessary for a better design, one that supports adjustable phase back for external beam optimization.

4. The question of whether to have an interpolator circuit, the best location for such as circuit and what rate to run its clock relative to the gauss steps, should be reviewed.

5. What is the best location for the phase input sensor? Should we be using a PUE or a current transformer?

6. What is the best choice of phase detector circuits, center-of-mass, or perhaps zero crossing? What is the best choice of limiter circuit and where should that circuit be inserted? Where should the gain of the pickup electrode amplifier be inserted? Should one use a phase detector that nulls at Ø or 9Ø degrees? Of some importance is the range of the phase detector: 18Ø or 36Ø degrees?

7. Reduction of frequency doubler distortion may give improved performance. Will a phase inversion at the doublers output result in a reduction in required detector range?

8. The "learn" circuitry has yet to be checked., The proper usage for this mode has to be established.

9. The general purpose analog input channel was never completed; this work must be done.

10. The auxiliary low level rf needs monitor improvements related to function generator rates and memory size. The analog signal multiplexer (rf unit) needs clean-up and operational testing.

CONCLUSIONS

We now have an operational model of a computer driven low level rf system. Based upon information and lessons learned during the recently concluded heavy ion beam commissioning studies, a project should now begin to design a pair of deliverable systems which will be constructed to be electronically and mechanically "clean" and thus capable of long service life, as well as being easily and rapidly repaired.

The materials cost for this effort, two new and complete llrf systems, is less than $10,000. The manpower to construct the new systems is of more concern. At least 12 man-months will be needed to achieve this goal. Training, maintenance and the generation of diagnostic programs will require an additional level of effort of 0.5 man-years of engineering and 0.5 man-years of technician resources during the first year of operation, and a total of 0.5 man-years per year thereafter.

This project should conclude with equipment operational for both open and closed loop operation and for both proton and HI applications. Success must be defined to include FULL documentation for operations release and spare arts for minimal down time and rapid repair of malfunctions.

I would like to take this opportunity to thank those whose efforts contributed to the success of the low level task force. It was an effort which showed the AGS Department at its best and all involved should be proud of their performance.

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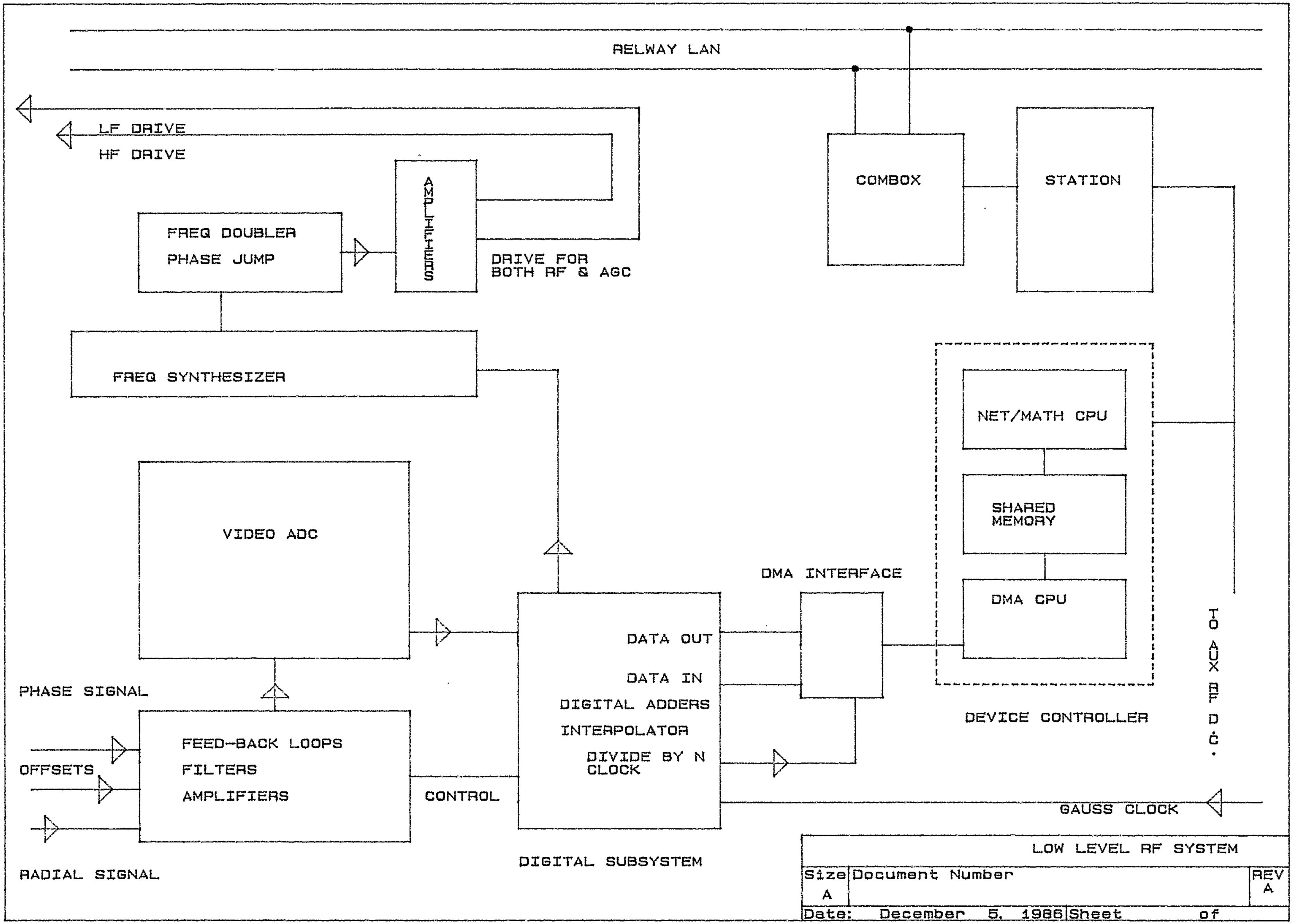
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